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Spheroid ages, kinematics, and BH relations

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Abstract. I very briefly discuss the ages and kinematics of spheroids as well as the black hole relations, via a few recent and illustrative studies, which include results on the downsizing, scaling laws, angular momentum and central massive objects.

Keywords. Galaxies: evolution, galaxies: formation, galaxies: bulges, galaxies: nuclei, galaxies: kinematics and dynamics

1. Formation, evolution and downsizing

The present paradigm for the formation and evolution of spheroids accepts mergers as a major contributor of the game. The intuitive idea that the most massive systems systematically form last is now clearly revoked by observations and numerical simulations (see e.g., Treu et al. 2005), and "downsizing" became a fashionable (revived) term. The question is then whether we can or not trace the formation history of spheroids via observations and models of their stellar populations and kinematics (e.g., Thomas et al. 2005; Cappellari et al. 2006; Rettura et al. 2006).

2. Ages of present-day early-type galaxies: going red?

Galaxy evolution in clusters, and more specifically the merger rate, is expected to be different than in lower density environment. Observations of a sample of galaxies in low density environment (Collobert et al. 2006) have thus shown overall younger stellar populations though with a greater age spread (see also Kuntschner et al. 2002). The SDSS view (up to $z \sim 0.1$; Clemens et al. 2006) then suggests that metallicity and α-enhancement are mostly driven by velocity dispersion (mass), but that only age is really significantly dependent on the environment (galaxy density; see also Nelan et al. 2005; Bernardi et al. 2006). This was confirmed in the study by Gallazzi et al. (2006) of the SDSS colour-magnitude and Mg-σ relations, which revealed that the later is indeed mainly a mass sequence, a tighter correlation being obtained when introducing the dynamical mass. The ratio between the stellar mass and the dynamical mass decreases with mass, which may be interpreted as an increase of the dark matter contribution for more massive early-type galaxies. Baldry et al. (2006) also showed that galaxy density Σ could in fact serve as a parameter seconding mass to explain the fraction of galaxies in the red sequence. These observational results all require a significant role from an efficient mass dependent feedback mechanism.

Faber et al. (2005) discussed several relative paths which would transform galaxies from the blue cloud into galaxies of the red sequence, including efficient quenching of star formation, plus wet and/or dry merging. In this context, stars in the discs and spheroids should end up with a different formation history, a result emphasised for nearby early-type galaxies by Kuntschner et al. (2006) via integral-field spectroscopy. Semi-analytic models (e.g., Springel et al. 2005) now include some specific treatment for quenching via

AGN (e.g., Croton et al. 2006) which allows one to follow the star formation history of a large sample of galaxies with widely different global properties. This led to and confirmed the important realisation that the assembly time does not correspond to the formation time (of the stars), with massive ellipticals forming their stars early but being assembled late (De Lucia et al. 2006).

3. Scaling relations

Early-type galaxies follow global relations which may be used, when linked with e.g., information on their stellar population, to constrain both their internal structure and formation history. One of the most powerful relation is the fundamental plane (FP), recently discussed by Cappellari et al. (2006) who showed that the tilt of the FP with respect to the law expected from the Virial Theorem is due mostly to an intrinsic variation of the mass-to-light ratio, with a maximum contribution of 6% from non-homology. The building of state-of-the-art dynamical models also recently allowed Cappellari et al. (2007, submitted to MNRAS) to suggest a possible link between anisotropy and intrinsic flattening. A new quantification of the specific angular momentum of such galaxies finally revealed that fast and slow rotators may have different formation origins, with an overall trend for slow rotators to be more massive (Emsellem et al., 2007, submitted to MNRAS). Such information is key to reconstruct a self-consistent scenario for the formation and assembly of early-type galaxies, including mass-dependent criteria for the onset of a feedback process and the characteristics of the merged progenitors. The fact that all slow rotators contain kinematically decoupled cores (KDCs, Emsellem et al., 2007) may then be explained by the (often underestimated) importance of multiple mergers (Bournaud, private communication), although more detailed numerical simulations in a cosmogical context (merger tree) are required to confirm this result.

4. Black hole relations

Central massive black holes seem to be ubiquitous in nearby galaxies, and their mass correlate with various properties such as bulge luminosity (Magorrian et al. 1998) or mass (Marconi and Hunt 2003), stellar velocity dispersion (Ferrarese and Merritt 2000; Gebhardt et al. 2000), or luminosity concentration index (Graham et al. 2001, Graham and Driver 2006). Still, only a few (mostly early-type) galaxies have well-constrained black hole masses (M_{bh}), and progress is clearly required both in terms of more realistic dynamical modelling and better data. The combined use of integral-field (IF) and high spatial resolution data is one step forward (e.g., Shapiro et al. 2006). The recent advent of adaptive-optics driven spectroscopy (Houghton et al. 2006) and even IFS (Neumayer, in prep.) will also help in this context, although such techniques may be restricted for some time to a few specific cases.

The power-law relation between M_{bh} and σ has recently been revisited by Wyithe (2006a, 2006b) who finally found no significant evidence for a log-quadratic term in the M_{bh}-σ relation. A similar approach was recently applied by Graham and Driver (2006) on the M_{bh}-Sersic n relation, for which a second order term seems to be required. This may significantly influence our view of the high and low mass ends of the M_{bh} spectrum. An extension of such a relation has been recently worked out by Zaritsky et al. (2006) who advocated the existence of a fundamental manifold uniting all spheroids present in dark matter halos. Lauer et al. (2006) also suggest that the M_{bh}-L relation may be in conflict with the M_{bh}-σ relation, suggesting the latter to lead to a significant underestimate of the black hole masses at the high end (for e.g., brightest cluster galaxies). An alternative view emerges from a study by Bernardi et al. (2006) who revealed a bias in the M_{bh}-L relation and favoured the M_{bh}-σ as a more fundamental relation. The evolution of the black hole mass with time was studied by Malbon et al. (2006) who estimated that growth via direct accretion is dominant over growth via mergers only for low mass black holes. Then, Ferrarese et al. (2006) and Wehner and Harris (2006) revealed that central massive (stellar) objects (CMOs) follow the same relation than massive black holes, suggesting a unifying mechanism for both nuclei and central black holes (see also Graham and Driver 2006). This may again reflect a mass-dependent phenomenon. It may therefore be interesting to look for a link between the proposed AGN-driven quenching scheme, the galaxy merger trees and the formation of central mass concentrations.

5. Conclusions

In this short paper, I tried to provide a brief updated view on spheroids. We now have a better understanding of the downsizing issue, which should certainly not be interpreted as an anti-hierarchical process. Environment and mass are key drivers of the age and chemical composition of spheroids. A new key parameter for galaxy evolution may in fact be found in the amount of baryonic angular momentum. More work is required to understand the observed relations with supermassive black hole masses, particularly at the high mass end, as well as regarding the link between nuclear black holes and CMOs. Mentioned issues, such as the existence of the blue and red sequences, the tilt of the FP, the properties of fast and slow rotators, the black hole (and CMO) relations, all point towards a picture in which galaxy formation and evolution has been strongly influenced by some efficient, mass-dependent, feedback mechanism. I would finally like to emphasise the need for a more physically motivated quenching scheme, which should allow us to design convincing and tasty recipes to be implemented in cosmological simulations.

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Discussion

Mike Dopita: I am glad you emphasised the need for physical models of AGN feedback. The observations of high-z radio-galaxies show that this feedback leads to violent star formation along with the matter ejection. Do you know of any observations that could reveal the fossil evidence of this star-formation episode?

Eric Emsellem: Not really, but I must admit I may not be the right (competent) person to answer that question. My gut feeling is that, on one hand, we should not expect much fossil evidence for such episodes in the local Universe, first because the information has been "smoothed" out since then, but also because it would be extremely difficult to disentangle the contribution from AGN-induced star formation from other mechanisms. On the other hand, a specific and more direct signature of such violent episodes may exist (since it does make a difference in the shaping of the hosts in terms of energy budget and colour/stellar population). To my knowledge, there is so far no such obvious signature to look for.